Wear 370-371 (2017) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Specific energy and the modified rubber wheel abrasion test

Zhihan Lin, T.G. Joseph, M. Curley*

University of Alberta, Edmonton, Alberta, Canada T6G 2R3

ARTICLE INFO

Article history:
Received 11 October 2016
Received in revised form
31 October 2016
Accepted 5 November 2016

Keywords:
Dry-sand rubber-wheel
Modified rubber wheel test
Abrasion
Specific energy
Hardfacing

ABSTRACT

In the oil sands industry a single ultra-class shovel tip can lose more than 35 kg of steel mass in one operating day. Equipment downtime is significantly increased with frequent stoppages to replace worn shovel teeth. This leads to a substantial loss in shovel availability and utilization, as well as a considerable increase in consumable cost.

This paper develops a means to predict the wear performance of shovel tips based on field data through the use of specific energy (*Es*), which is defined as the friction energy required to cause a unit volume loss of material (Nm/m^3). A modified rubber wheel abrasion test (similar to ASTM-G65) is presented for the determination of *Es*. Results show that it is possible to predict the performance of shovel tips. It is also found that *Es* provides an index to quantify the resistance of wear materials to abrasion under specific abrasive conditions.

1. Introduction

Electric cable shovels are the most commonly used ultra-class scale excavation equipment in the oil sand mining industry. In the Athabasca oil sand region of Northern Alberta, Canada, the application of cable shovels has proven very effective. However, severe wear caused by interactions between shovel tips and abrasive media leads to significant expenses related to equipment maintenance and production loss. The study of abrasion is of major interest to the mining industry; however, most research has previously concentrated on the theoretical analysis and establishment of micro-scale models, which are difficult to validate for engineering purposes. Some research has aimed to improve wear resistance of materials by means of chemical technologies, which is time consuming and cost intensive. A simple but practical method to facilitate selection of materials to match actual abrasive conditions encountered in the field has been targeted in this paper to realize greater performance from ground engaging tools with little investment.

The goal of this study was to investigate a scaled abrasion test to measure specific of energy wear resistant materials interacting with abrasive media and to apply the concept of specific energy to wear life predictions for the ground engaging tools (GET) operating in the Alberta oil sands.

1.1. Background

Oil sands are complicated mixtures of quartz, bitumen, and water with quartz accounting for greater than 80% of the total solids and acting as the predominant abrasive and erosive media [1]. 99% of quartz grains in oil sand are waterwet; with the bitumen occupying the interstitial space and a water phase forming a film around the grains. Ground engaging tools mounted on cable shovels operating in oil sand are subjected to severe abrasive wear damage caused by these hard quartz particles. Oil sand displays high shear strength but minor cohesion, with no adhesion damage to ground engaging tools. The abrasive particles are hard but with varying size and shape which makes the application of the accepted G65 rubber wheel abrasion test less than ideal.

2. Abrasive wear

Abrasion, defined as the removal of materials from an abraded surface, is the most common form of wear attack in earthmoving, mining, and mineral processing equipment. For cable shovels and other ground engaging tools, severe abrasion is caused by the interaction between the surface of the shovel teeth and ground. Penetration by hard quartz particles creates plastic deformation of the softer tooth material, which when coupled with sliding motion, results in material removal. Abrasion can be classified as low-stress abrasion, high-stress abrasion, or gouging abrasion according to the degree of severity [2–4]. These three forms of abrasion are encountered by ground engaging tools. Generally, shovel teeth

---

* Corresponding author.
E-mail address: mcurley@ualberta.ca (M. Curley).

http://dx.doi.org/10.1016/j.wear.2016.11.002
0043-1648/© 2016 Elsevier B.V. All rights reserved.

Please cite this article as: Z. Lin, et al., Specific energy and the modified rubber wheel abrasion test, Wear (2016), http://dx.doi.org/10.1016/j.wear.2016.11.002

are subjected to low-stress abrasion in soft and free excavated materials like oil sands, whereas high-stress or gouging abrasion can occur during excavation of hard, blasted minerals. The actual mechanism with which abrasion works is highly dependent on both the abraded and abrasive material properties but can be characterized as: micro-ploughing, micro-fatigue, micro-cutting and micro-cracking [5].

2.1. *Abrasive failure of shovel teeth*

In the mining industry, ground engaging tools are subjected to heavy abrasive damage due to severe interactions between teeth and ground. The occurrence of abrasive wear on shovel teeth not only reduces a shovel's operating efficiency, but also leads to significant production loss due to unplanned maintenance. Knights [6] showed that a set of nine teeth was only worth US $2700, but the average production lost caused by an unplanned change-out of a tooth set was US $38,000 [6]. Even though properties of materials such as toughness, ease of fabrication, and weldability have an influence on the performance of ground engaging tools, hardness is the most significant factor considered [1]. In an effort to increase abrasive resistance of shovel teeth, martensitic steel castings have been suggested as the substrate materials, with hardfacing materials employed as protective coatings. Martensitic steel castings have a unique combination of relatively high hardness, suitable toughness, and ease of fabrication; thereby providing an appropriate substrate material for a shovel tooth. Martensitic steels belong to the medium carbon material class of steels with up to 4% alloy [7]. Depending on the digging condition, various combinations of toughness, hardness, weldability, and strength of martensitic steels can be achieved through metallurgical techniques such as alloying and heat treatment. Hardness' fall in the range of 243–560 HV; much lower than quartz at 850–900 HV. Since quartz sands are the dominant abrasive constituents in oil sands, hardfacing is typically applied to enhance wear resistance and to approach the hardness requirement in practice.

The most widely used hardfacing technique is welding deposition. Hardfacing has many advantages including a large range of achievable hardness, corrosion resistance and the ability to permit repairs. The hardness of welding deposits ranges between 513 and 800 HV. Chromium carbide or chrome white irons are the most common hardfacing welding consumables [2,7]. More recently developed consumables include tungsten carbide-based materials, which contain up 75% tungsten carbide particles that have a hardness up to 1900 HV; providing extreme abrasion resistance for shovel teeth. Hardfacing drawbacks include the possible occurrence of cracking, especially on thick deposits, and the influence of high welding temperatures on the microstructure of substrates [8].

2.2. *Existing abrasion tests*

The two most commonly used abrasion tests are the jaw crusher gouging abrasion test (ASTM-G61) and the dry sand rubber wheel test (ASTM-G65) [9,10]. The jaw crusher gouging abrasion test is primarily used to study the wear of ground engaging tools interacting with hard and large abrasives representing conditions commonly associated with quarry and metallic mineral mining operations. For the case of fine abrasives such as oil sands, the dry sand rubber wheel (DSRW) test is more suitable as there is little occurrence of breakage during excavation in a soft abrasive medium like oil sands.

The dry sand rubber wheel setup is shown in Fig. 1. The general procedure for the ASTM-G65 test consists of the following steps: cleaning and weighing the specimen; fixing the specimen in the holder and loading a set force between the specimen and the rubber wheel; setting the revolution counter; adjusting and starting the sand flow; starting the wheel rotation; stopping the drive motor after running the desired number of wheel revolutions; and removing, cleaning and reweighing the specimen. The dry sand/rubber wheel test should be only used for wear ranking, not for specifying absolute wear values. Therefore, to mimic actual circumstances, variants of the standard procedure must be made to obtain the type of wear information required for engineering purposes. Aside from changes in the loading weight and sliding distance, the rate of sand flow, abrasive characteristics, and test duration can be reconfigured. Research has shown that approximately 200 wheel revolutions is adequate to create a steady wear rate and that multiple shorter tests could be run instead of a single long test to protect the rubber wheel [11].

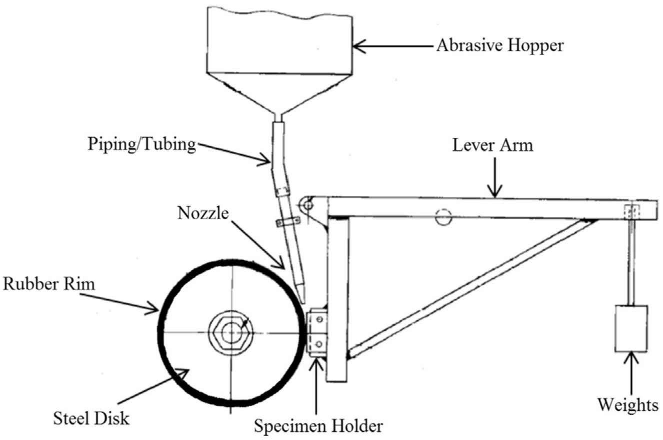

Fig. 1. Dry sand/rubber wheel abrasion apparatus (Adapted from ASTM G65).

2.3. *Relationship between abrasion and energy*

Abrasive wear can be described as a hard conical particle penetrating and sliding within a softer material as shown in Fig. 2. In a typical abrasion function, (1), the abrasive wear is quantified as a volume loss generated by a single conical particle sliding over a distance L_i [12,13].

$$V_i = \frac{2}{\pi \cdot \tan\theta} \cdot \frac{W_i L_i}{H} \tag{1}$$

Eq. (1) is the typical abrasion function, where $2/(\pi \cdot \tan\theta)$ represents a wear coefficient and is dependent on the ductility of the

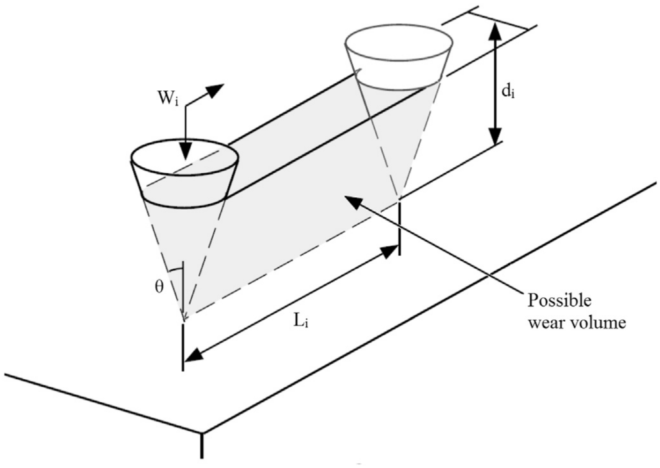

Fig. 2. A typical model of abrasive wear by a conical particle (after [12]).

Please cite this article as: Z. Lin, et al., Specific energy and the modified rubber wheel abrasion test, Wear (2016), http://dx.doi.org/10.1016/j.wear.2016.11.002